International Journal of Engineering Research and Development
e-ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 10, Issue 9 (September 2014), PP.69-76

Macro Mechanical Properties of Ultra High Strength Concrete Using River Sand and Silica Fume

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Abstract:- Ultra High Strength Concrete (UHSC) is a new generation of concrete which has exceptional mechanical and durability properties. The major difference between ultra high strength concrete and conventional concrete is that coarse aggregates are eliminated in UHSC which improves the homogeneity of concrete. The present paper is aimed to produce ultra high strength concrete using locally available materials, to achieve target compressive strength more than 170 Mpa. Different curing regimes play different role in enhancing the micro structural properties of concrete which improves the mechanical and durability properties of concrete, apart from different curing regimes a combination thermal curing regime and normal water curing has been chosen. A cube specimen of size 70.6 mmX 70.6mmX70.6mm mm and cylindrical specimen of size 100 mm diaX 200 high mm were cast and demoulded after 24 hours then they allowed for normal water curing. Specimens were exposed to thermal regime at 200^0C for duration of 24 hrs, 48 hrs and 72 hours at the age of third day followed with water curing till 28 days. The compressive strength varied in the range of 108 Mpa to 171 Mpa. The results showed marked difference in compressive strength and split tensile strength of UHSC with thermal curing when compared with only normal water curing.

Keywords:- UHSC, Silica fume, Quartz powder, Thermal curing regime, compressive strength.

I. INTRODUCTION

Concrete is one of the necessary elements for structural work in the modern construction. In the decade, buildings around the world have become higher and so the structural strength demand for concrete is increased as they require high strength concrete. Ultra high strength concrete (UHSC) has been developed in the recent revolution of concrete. The major difference between ultra high strength concrete and conventional concrete is that no coarse aggregate is involved in ultra high strength concrete, but crushed quartz, quartz powder and fine river sands are used instead, with high dosage of silica fume. UHSC has exceptional mechanical properties and durability, ingredients of its includes cement, silica fume, quartz powder, quartz sand/river sand, steel fibres and it's also called as Ductile concrete due to it's high capacity to take load, deform and even support flexural tensile load after initial cracking. UHSC will be suitable for pre-stressed application and for structures acquiring light weight and their components such as roofs, stadiums, longer span bridges, space structure, high pressure pipes, blast resistance structure and containment of nuclear wastes

The most important property of UHSC is self healing potentiality. Talking into sustainability point of view, UHSC has cement about two times of ordinary concrete thus it requires more energy and produces more CO_2 but it has exceptional durability properties minimizing the maintenance cost for the life time of the structure.

Prabhat et al[1] investigated the influence of curing regimes on ultra high performance concrete and assed the optimal duration of thermal curing regime to attained maximum compressive strength. M.M.Reda et al.[2] reported the macrostructural investigation on ultra high performance concrete and UHPC has excellent durability properties and used to produce high-strength precast elements. Richard and Cheyrezy [3] developed ultra high strength ductile concrete with the basic principles of enhancing homogeneity by eliminating the coarse aggregate and enhancing the micro structure formation by post-set heat treatment, RPC has concrete remarkable flexural strength and very ductility. Harish K.V et al. [4] studied the choice of ingredients and curing regimes of ultra high strength concrete and found a combination of normal water curing,hot water curing and hot air curing to be the optimum curing regime to attain high strength. Chi-ming tam et al.[7] conducted heat treatment with different temperatures on RPC and found that increasing temperature required long duration to achieve .K.M Nag et al . [9] Investigated the production process of RPC and made comparisons of RPC and HPC and was found that mechanical properties of RPC greater than HPC. Dilli and manu santhanam [10] developed two RPC mixes of 200 Mpa and 800 Mpa, the workability and durability properties of RPC and said that RPC has very low chloride ion permeability. J.K. Dattareya et al. [12] studied the use of particle packing for mix proportioning of RPC and different materials of loose packing density and vibrated packing density considered in producing RPC. Chan y.w and chu S.H.[5] reported that by the presence of silica fume in concrete that which enhances the steel fibre matrix bond due to the interfacial-toughening of effect upon fibre slip.

In all the previous studies quartz sand was used as fine aggregate but in the present study river sand is used. This paper aim to achieve the following objectives

- To examine the influence of Quartz powder on compressive strength of UHSC
- To investigate the effect of Thermal curing regime on compressive strength of UHSC
- Suggesting optimal duration of thermal curing regime

II. MATERIALS USED AND THEIR PROPERTIES

In this paper, ingredients used in preparing UHSC mixtures are different from conventional concrete. The materials include Cement, Silica fume (SF), Quartz Powder (QP), sand, steel fibers, Super plasticizer and Water. Details of each constituent are as follows. Table 1 and table 2 shows the properties of Super Plasticizer and Silica fume.

A. Cement

The ultra Tech 53 grade ordinary Portland cement was used during the experiments which conforms to IS:12269-1987. The specific gravity 3.14; the initial and final setting times are 120 min and 255 min.

B. Silica fume

The silica fume was used in this experiments conforms to ASTM C 1240 and IS 15388:2003. The specific gravity 2.63: Moisture content 0.058%; Pack density 0.76 gm/cm^3. The silica fume is extremely fine particle size of 0.5µm-1µm, which exists in white color powder form. Silica has been procured from Astrra chemicals Ltd-Chennai:

C. Quartz Powder

The specific gravity 2.6 and it is in White colour powder form and has particles size ranging from 20µm-45µm

D. Sand

The river sand used for the experimental studies are Grade 1 (particles size ranges from 600µm- 1.18 mm) and grade 2 (particle size ranges from 300µm-600µ) which conforms to IS 383:1970.

E. Super plasticizer

Master Glenium ® sky 8233formely B-233 which is poly-carboxylic ether based hyper super plasticizer procured from BASF India Ltd construction chemicals-Secundarabad

F. Steel fibers

Hook end fibres are used in this study which have dia of 0.45mm, length of 30 mm and aspect ratio of 67 and procured from Dura flex steel fibres reinforcement redefined proceeded by kasturi composite pvt Ltd, Amravati Maharashtra India,

Table 1 Properties of Silica fume

Sl. No.	Properties	
1	Form	Ultra fine amorphous powder
2	Colour	White
3	Specific gravity	2.63
4	Pack Density	0.76 gm/cc
5	Specific surface	20 m^2/g
6	Particle size	15µm
7	Sio_2	99.89%

Table 2 Properties of Super plasticizer

Sl. No.	Properties	Glenium B-233
1	Type of SP	polycarboxylic ether
2	Appearance	Light brown
3	PH value	≥6
4	Specific gravity	1.08
5	Solid content	less than 30% by weight
7	Chloride content	<0.2%

III. EXPERIMENTAL PROGRAMME

A. *Mix proportion*

The mix design of UHSC based on the reference mixes available in the literature and various trail and errors had done at the laboratory. It is identified that Silica fume/Cement ratio and Quartz powder/Cement ratio 0.25 and 0.4 respectively (Richard and Cherzy, 1995; Ductal et al, 1995; Dill and Santhanm, 2004; Graybel, 2007; Prabhat Ranjan et al, 2013). The optimal dosage of Steel fibre ratio is 2% by volume or about 156 kg/m^3. Table 3 shown USHC mixes used in this present study

Table 3 shows mix proportion of UHSC

Mix ID	RS-1 30% QP	RS-2 35% QP	RS-3 40% QP	RS-4 45% QP
Materials	Kg/m^3	Kg/m^3	Kg/m^3	Kg/m^3
Cement	750	750	750	750
Silica Fume	187.5	187.5	187.5	187.5
Quartz Powder	225	262.5	300	337.5
River Sand	1010	972	934.2	896.3
Steel Fiber	156.2	156.2	156.2	156.2
Super Plasticizer	11.25	11.25	11.25	11.25
Water	187.5	187.5	187.5	187.5
W/B Ratio	0.2	0.2	0.2	0.2

B. Mixing sequence

Since UHSC is composed of very fine constituents the conventional mixing is not appropriate, so the mixing method can't be the same. The following sequence in mixing UHSC is based on the previous studies and our own trails at laboratory.

- A pan mixer of 100 kg capacity was used to mix UHSC, having RPM of 300
- Mixing all dry powders includes cement, silica fume, quartz powder and river sand for about 5min
- Addition of half the volume of water containing of SP, mixing it for about 3 min
- Addition of remaining water and super plasticizer; mixing is continued for until uniform mixture was achieved which has flow able self compacting consistency.
- Finally steel fibres were added when the flow able consistency was achieved.

Fig 1 shows Flow ability of the USHC

C. *Specimen preparation and curing*

For each mix of concrete, 4 sets of samples were cast, each set contain 3 cubes (70.6mmX70.6mmX70.6 mm) and 3 cylinders of size (100 mm dia. X 200 mm high),demoulded after 24 hours then they were allowed for normal water curing for one day. At the age of third day 3 sets samples were exposed to hot air oven curing at temperature of 200^{0}C. One set of samples were taken from the oven when they had cured for 24 hours, after which they were allowed to attain thermal equilibrium with atmospheric temperature and then kept in water till the date of testing. Similarly second set and third set samples were taken out from the oven when they had thermally cured for 48 hours and 72 hours respectively, after which they allowed to attain thermal equilibrium and then kept in water till the age of 28 days. One set of samples completely cured in normal water.

D. Testing

Cubes of size 70.6 mmX70.6mm X70.6mm were tested to compute compressive strength and cylinders of size 100 mm diaX200 high were tested to compute split tensile strength of concrete. Both specimens were tested under the Compression testing machine of 2000 KN capacity. Average of 3cubes compressive strength and 3 cylinders split tensile strength are tabulated.

E. Theoretical modulus of elasticity

Theoretical Modulus of elasticity of UHSC is calculated using the empirical formula which is given by ACI 363R-92[9.99]

E_c=3.65X$f_c^{0.5}$---------------- (1)

Where E_c= Expressed in GPa

F_c= Compressive strength in MPa

Substituting the compressive strength values in the above equation 1 the modulus of elasticity is calculated.

IV. RESULTS AND DISCUSSION

A. Production process

By physical observation during concrete mixing, a long time is required for UHSC mixes to ensure that self flow able self-compacting consistency. The total mixing time is 15 min; the long time mixing is necessary for dispersing silica fume, quartz powder and steel fibres in well manner.

B. Thermal curing regime

Thermal curing of Ultra-High strength concrete (UHSC) has a strong influence on its mechanical properties and lead to a significant improvement of the degree of hydration of the cement paste. Increasing temperature accelerates the formation of crystalline calcium silicate hydrates by dehydrating the cement paste and ends in the formation of Tobermorite, Xnotlite, Scawtite. Thereby the micro structure undergoes an obvious change. Cement paste consists of close networked crystal fibres with dimensions up to 1 μm. By filling cracks and small pores with crystalline C-S-H phases, flaws in the matrix are removed and generate a more homogeneous micro structure. High temperature accelerates the pozzalanic reaction of silica fume and quartz, at normal temperature quartz will only act as filler material. On continued heating of around 200^{0}C, Cao/SiO_2 ratio reduces and C-S-H ultimately converts into xonotlite and smaller amount of Tobermorite which is having very dense micro structure (Richard and cherzy(1995), Redda et al(1999),Chi-ming tam et al(2012) Kamen et al(2007))

The following stoichiometric equations are involved in the hydration of cement

$2(3CaO.SiO_2)+6H_2O \rightarrow 3CaO.2SiO_2.3H_2O+3Ca(OH)_2$

$2(2CaO.SiO_2)+ 4H_2O$ $3CaO.2SiO_2.3H_2O+Ca(OH)_2$

$3Ca(OH)_2$+Silica fume+$H_2o \rightarrow 3Cao.2sio_2.3H_2o$

(Secondary hydrates)

6SiO2 + Ca(OH)2 $\rightarrow$ 3(5CaO.6Sio2.5H2O)

(Quartz powder) (1.3 nm Toberomorite)

8SiO2 + Ca(OH)2 $\rightarrow$ 3(5CaO.6Sio2.5H2O)

(Ground Quartz)

$C_5S_6H_5 \xrightarrow{150^0C} C_3S_2H_3$(1.3nmToberomorite)

$C_5S_6H_5 \xrightarrow{200\ ^0C} C_6S_6H_5$(smallerxonotlite)+$C_3S_2H_3$

$C_5S_6H_5 \xrightarrow{250\ ^0C} C_6S_6H_5$(xonotlite)

$C_5S_6H_5 \xrightarrow{>250\ ^0C} C_7S_6CH_2$(Scwatite)

C. Mechanical properties

The test results of compressive strength, and split tensile strength and theoretical modulus of elasticity for corresponding mixes are tabulated.

Compressive strength test results are shown in table 4 and fig no 2. The compressive strength results shows that there is good positive effective of increasing quartz powder content up to 40% by weight of cement. The main reason for the increase in compressive strength is due to the physical effect of quartz powder grains that allows denser packing within the cement particle and quartz powder also acts as pozzalanic materials at higher temperature and improves the micro structure which leads to increase in compressive strength

Table 4 Compressive strength results in Mpa

Mix ID	RS-1	Rs-2	RS-3	RS-4
NWC	107	108	108	98
Thermal curing at one day	157	159	164	154
Thermal curing at two days	154	138	167	156
Thermal curing at three days	158	154	171	139

Split tensile strength results are shown in table 5 and fig no 3. The split tensile strength of UHSC is more than that of conventional concrete. It was recorded that maximum split tensile strength is 20 MPa for RS-3 mix with 2 days thermal curing. From the results it can be observed that split tensile strength of concrete increased in line with compressive strength.

Table 5 split tensile strength results in MPa

Mix ID	RS-1	Rs-2	RS-3	RS-4
NWC	15	9	12	10
Thermal curing at one day	10	11	14	12
Thermal curing at two days	15	9	20	13
Thermal curing at three days	12	13	16	12

The theoretical Modulus of Elasticity results are shown in table 6 and fig 4. The increase in the quartz powder content has remarkable helpful effect on modulus of elasticity of UHSC samples. At 28days the modulus of elasticity values were increased by about 20% for 40% quartz powder content samples when compared with 30% quartz content samples which were cured in normal water. The maximum elasticity was recorded 48 Gpa for RS-3 mix samples.

Table 6 Modulus of Elasticity Gpa

Mix ID	RS-1	Rs-2	RS-3	RS-4
NWC	38	38	38	36
Thermal curing at one day	46	46	47	45
Thermal curing at two days	45	43	47	46
Thermal curing at three days	46	45	48	43

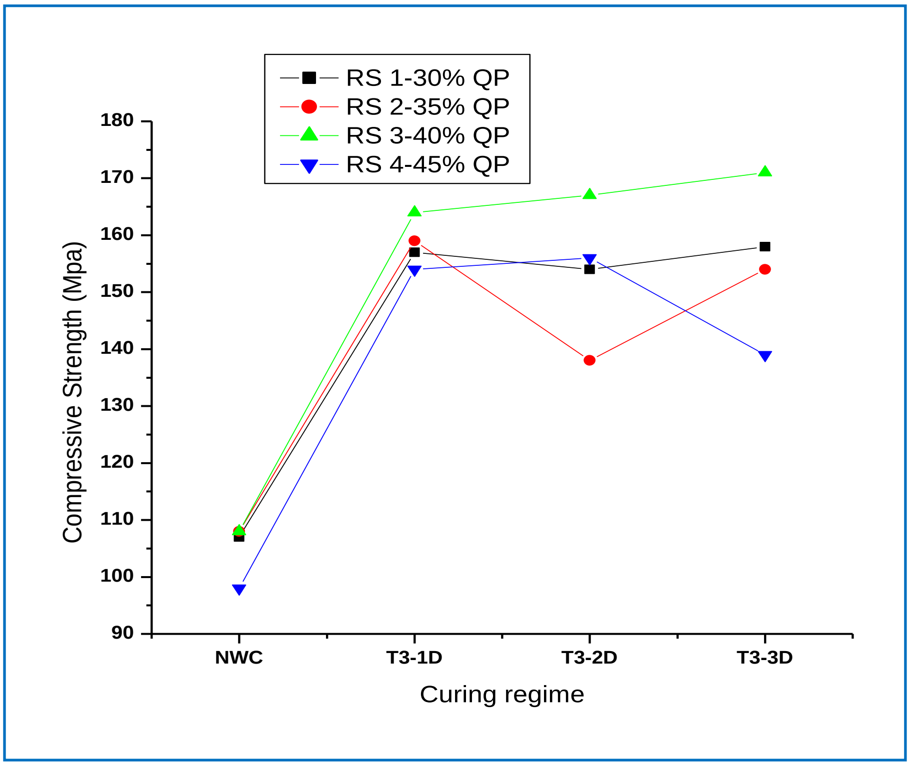

Fig 2 Compressive strength Vs Curing regimes

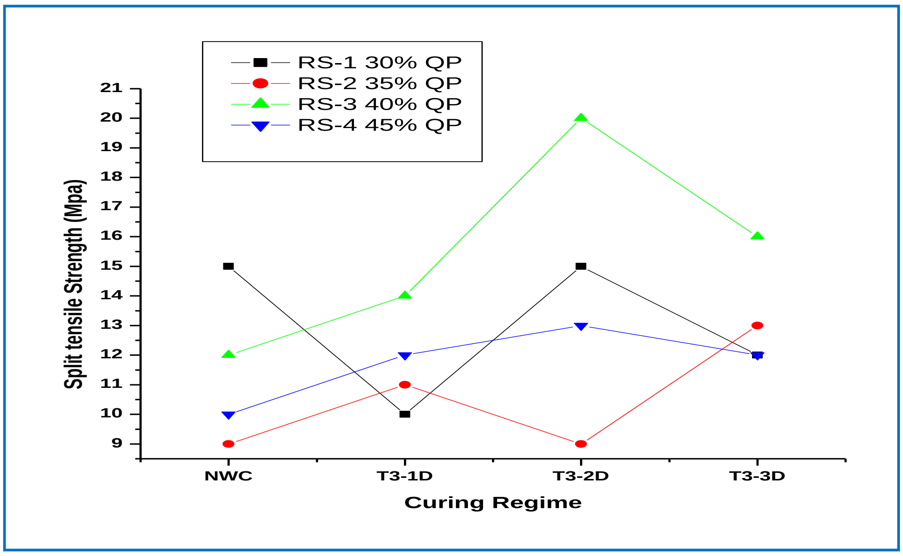

Fig 3 Split tensile strength Vs Curing regime

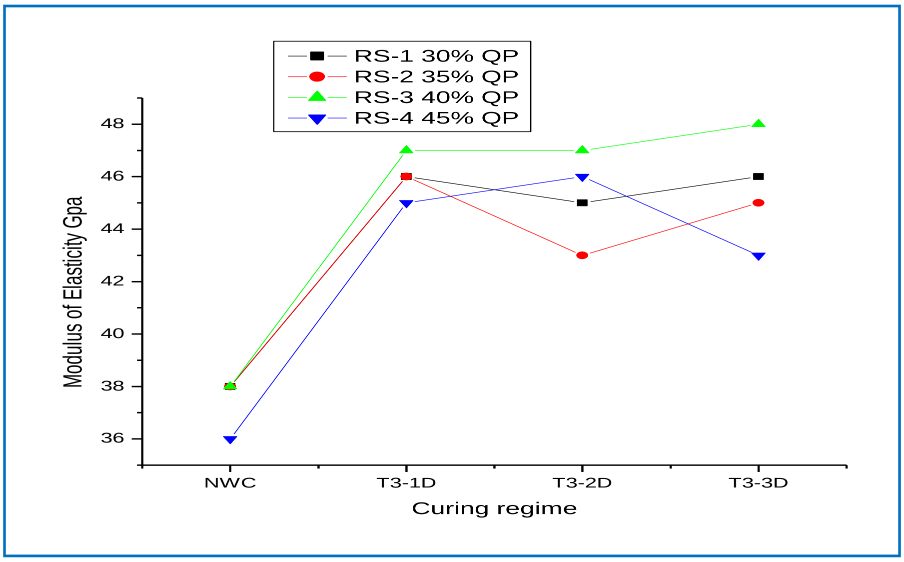

Fig 4 Modulus of Elasticity V_s curing regime

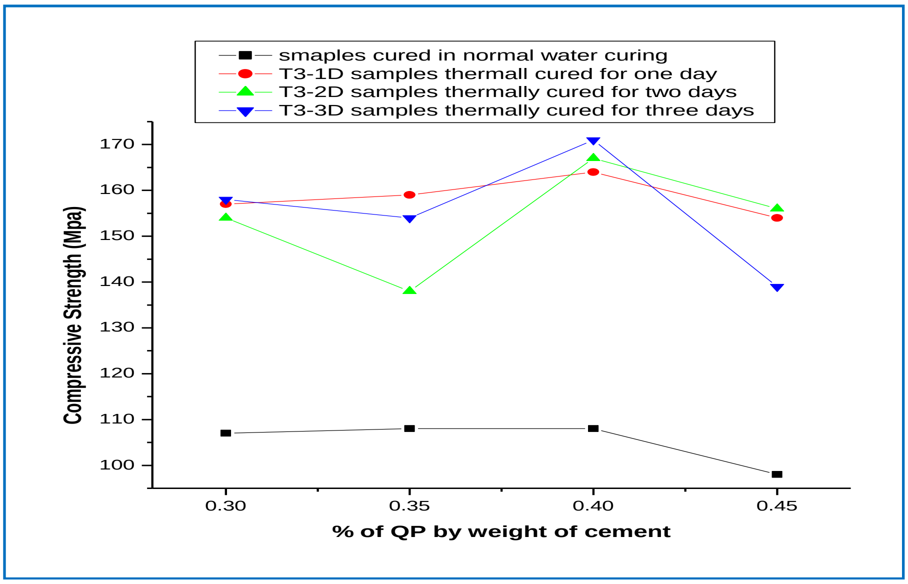

Fig 5 Compressive strength V_s Quartz powder

D. Density of UHSC specimens

The density of all specimens is varied between 23.3 - 26.0 KN/m^3

F. Effect of Quartz powder on compressive strength

Hydrated cement alone can't help to evaluate the compressive strength of UHSC but other parameters contribute marginally such as quartz powder types and curing regimes. Here quartz powder act as effective filler material at normal water curing and also it's act as a pozzalanic material at higher temperature. From the observations of following graphs, the addition of quartz powder produce the better results under the hot air oven curing than that of normal water curing. The results show that maximum compressive 171 Mpa is attained at quartz powder of 40% by weight of cement under the hot air oven curing condition. This is possible due to increased proportion of fine fillers that enhance the packing density, pore fill in action and long chains of C-H-S gel.

G. Effect of thermal duration on compressive strength

From the graphs, three day thermal curing regime gave good compressive strength results for the RS-3 samples which were having 40% quartz powder content when compared all other mixes at three days thermal curing. Compressive strength of RS-3 samples is more at one day, two days and three days thermal curing regime when compared all other mixes at one day, two day and three day thermal curing regime. For normal water curing, increasing quartz powder content has no effect on compressive strength so that thermal curing regime is necessary to activate the pozzalanic function of quartz powder.

H. Influence of curing regime

An adequate supply of moisture is essential to ensure that hydration is sufficient to reduce the porosity to a level such that the desired strength can be attained. The effect of normal water curing and thermal curing at various ages on compressive strength is shown. Thermal regime has a importance which activates the pozzalanic reaction of silica fume and quartz powder otherwise they will act as a filler not as a binder materials.

Thermal curing regime enhances the micro structural changes of hydrated structure. Increasing temperature and duration causing formation of different C-S-H gel crystal such as Tobermorite, Xonotlite and Scwatite these micro structural changes are investigated by SEM and XRD analysis. From the graph it is observed that thermal curing regime increase the compressive strength up to 37% nearly when sample compared of normal water curing.

V. CONCLUSIONS

In this paper the investigations of effect of increase of quartz powder and thermal curing on UHSC are presented.

The following conclusions can be summarized from the study.

- Ultra High Strength concrete can be produced using locally available materials.
- The maximum compressive strength of 171 Mpa is achieved for the mix with 40% quartz powder and 72 hr thermal curing.
- The maximum split tensile strength of 20 Mpa was achieved for the mix with 40% quartz powder and 48 hr thermal curing.
- The maximum modulus of elasticity of 48 Gpa was achieved for the mix with 40% quartz powder and 72 hr thermal curing.
- A combination of normal water curing and thermal curing was found to be the optimum curing regime in the present study. This combination has yielded good results compared with normal water curing.
- Silica fume is one of the main contributors to strength due to its high pozzalanic activity pore filling action, forms dense mixes and changes the miro structural formation.

NOMENCLATURE

USHC-Ultra high strength concret
RPC-Reactive powder concrete
UHPC-Ultra high performance concrete
SF-Silica fume
QP-Quartzpowder
NWC-Normal water curing
SP-Super plasticizer
T3-1D-samples thermally cured for one day after two days from the date of casting
T3-2D-samples thermally cured for two days after two days from the date of casting
T3-3D-samples thermally cured for three days after two days from the date of casting
Gpa-Giga pascal
Mpa-Mega pascal

REFERENCES

[1]. Prabhat R P, Bharatkumar B H and Iyer N R 2012 Mechanical properties of ultra high performance concrete. Proceedings of World Academy of Science, Engineering and Technology. No. 68. World Acad. Sci. Eng. Technol. 351(68): 1969

[2]. M.M Reda, Shrivea G N and Gillotta E J 1999 Micro structural investigation of innovative UHPC. Cem.Concr. Res. 29(3): 323–329

[3]. Richard P and Cheyrezy M 1995 Composition of reactive powder concretes. Cem. Concr. Res. 25(7): 1501–1511

[4]. Harish K V, Dattatreya J K and Neelamegam M 2007 Role of ingredients and curing regime in ultra high strength powder concretes. Journal of structural engineering vol.34,Feb-Mrch 2008.

[5]. Chan Yw, Chu SH. Efeect of silica fume on steelfiber bond characterstics in reactive powder concrete. Cement concrete Research 2004; 34:1167-72

[6]. S. Shaw , S.M. Clark, C.M.B. Henderson Hydrothermal formation of the Calcium silica hydrates, Tobermorite, xonotlite:an insitu synchrotron study, Elsevier, chemical geology 167 (2000) 129-140.

[7]. Chi-ming Tam, Vivian Wing-yan Tam Micro structural behavior of RPC under different heating regimes Magazine of concrete research vol 64 issue 3,2012.

[8]. Stephen Brunauei Tobermorite gel-the heart of concrete, Research and development laboratories of the port cement association, American scientist Vol. 50, No. 1, 210-229 (March 1962).

[9]. K. M. Nag, C. M. Tam and V. W. Y. Tam Studying the production process and mechanical Properties of reactive powder concrete, Magazine of Concrete Research, 2010, 62, No. 9, September, 647–654.

[10]. Dili A. S. and Manu Santhanam. (2004) "Investigation On Reactive Powder Concrete: A Developing Ultra High-Strength Technology" Indian Concrete Journal.

[11]. Harish K V et al., Role of ingredients and of curing regime in ultra high strength powder concretes, Journal of Structural Engineering, Vol. 34, No. 6, pp. 421-428, 2008

[12]. J.K.Dattatreya K.V. Harish,and Neelamegam,M.,(2007), " Use of Particle Packing Theory for the Development of Reactive Powder Concrete", The Indian Concrete Journal , September 2007, pp 31-45.

[13]. Methods of tests for strength of concrete, IS 516:1959, Bureau of Indian standard, New Delhi.

[14]. Properties of concrete by A.M Neville